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# Floating-fixed-bed-gasification: from vision to reality

Marcel Huber[a]*, Markus Huemer[a], Angela Hofmann[a], Sabrina Dumfort[a]

[a]*Management Center Innsbruck - Department of Environmental, Process & Energy Engineering, Maximilianstr. 2, 6020 Innsbruck, Austria*

## Abstract

Over the last years, numerous gasification concepts have been developed to a reliable and commercially available state leading to a strongly increasing numbers of built plants. One of these describes a novel way in the thermochemical gasification of biomass by using a unique reactor design and operational mode – the floating-fixed-bed reactor. Comparable gasification concepts show bottlenecks in downsizing possibilities and tar concentration in product gas from fluidized bed gasification as well as problems of channeling or compaction of the fuel bed in fixed-bed systems. The idea of the floating-fixed-bed reactor is to build up a stable bulk bed, which is floating on the inlet gas stream from pyrolysis and oxidation. Without uncontrolled particle movement in the reduction reactor and only relative movement of the fuel particles within the bed, relatively long gas residence could be provided, resulting in low tar concentrations in the product gas. The technology has proven the potential to bypass issues of comparable gasification technologies and verified the advantages of the innovative reactor design in several long-term test runs on pilot plants and also commercial plants. Beside continuous improvement of the gasification technology, the current development aims for upscale possibilities and increased fuel flexibility.



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* Corresponding author. Tel.: +43-(0)-512-2070-3223
*E-mail address:* marcel.huber@mci.edu



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## 1. Introduction

Multi-staged fixed-bed gasification systems represent one of the most promising and effective methods for transforming solid biomass into heat and power (CHP) at medium scale. The limitation in size and some other bottlenecks of conventional fixed-bed systems [1] have been successfully dealt with by the floating-fixed-bed gasification technology as described by Huber et al. [2].

Based on the findings with the first pilot plant, an Austrian consortium under the leadership of the MCI and supported by the Standortagentur Tyrol, initiated in 2009 the 3-year project PowerBox. Aim of the project was to verify the first findings with an upgraded setup of the demonstration plant under long-term conditions. During the three-year PowerBox project, the great potential of this highly innovative gasification concept has been demonstrated, but also restrictions concerning applicable biomass have been found.

In the follow-up project PowerBox², which was started in 2013, the adaption of the gasification setup and gasification reactor from wood gasification to the utilization of communal and agricultural biogenic residues will be dealt with. Investigations on the gasification behavior of straw raw material, regarding ash melting temperature and carbon conversion, show a significant influence of the biomass composition onto the gasification reactions. These effects caused by higher ash content and different ash composition, compared to wood, show a not negligible influence onto the operational parameters of the gasification setup.

## 2. Methods

The continuous operation tests have been done with standard spruce wood-chips classified G30-W10-S150 according to ÖNORM M 7133, still containing bark. The plant has been operated within an air ratio of 0.3 to 0.38. All mass and energy input and output flows were registered online. Beside the continuous analysis of the gas main components, almost all interesting gasification parameters like tar-loads, ammonia, etc. have been sampled and analyzed according to common standards and knowledge [3].

The core of the staged floating-fixed-bed technology is the floating-fixed-bed reduction reactor. Due to its unique design, it allows the gasification process to happen, contrary to a fluidized-bed, within a strict tubular reactor, preventing backwards exchange of fuel material and gas. The pyrolyzed particles enter the reduction reactor at the bottom and get integrated in the stable floating bulk. Due to the continuous feeding of the pyrolysis unit, new char particles enter the floating-fixed-bed and build up a new layer below the former bulk. This leads to an upward movement of the bulk to a new position, where a balance between the up- and downward forces exists (figure 1).

Compared to fixed-bed gasification systems there is no need for a grate to fix the bed position and no need for additional bed material, beside the pyrolyzed fuel particles, like in fluidized bed gasification. The porosity and position of the floating-fixed-bed within the reduction reactor is dependent on the gas stream produced in the pyrolysis und partial oxidation process step. A principal behavior of the floating-fixed-bed gasification reactor and its difference to a fluidized-bed or fixed-bed-reactor has been described by Kreutner et al [4].

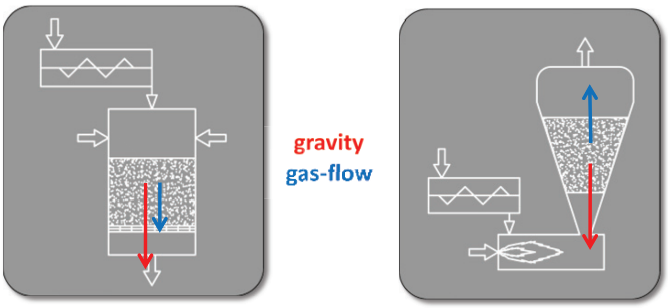


Fig. 1. Forces in a staged fixed-bed (left) and in a staged floating-fixed-bed (right) gasifier.

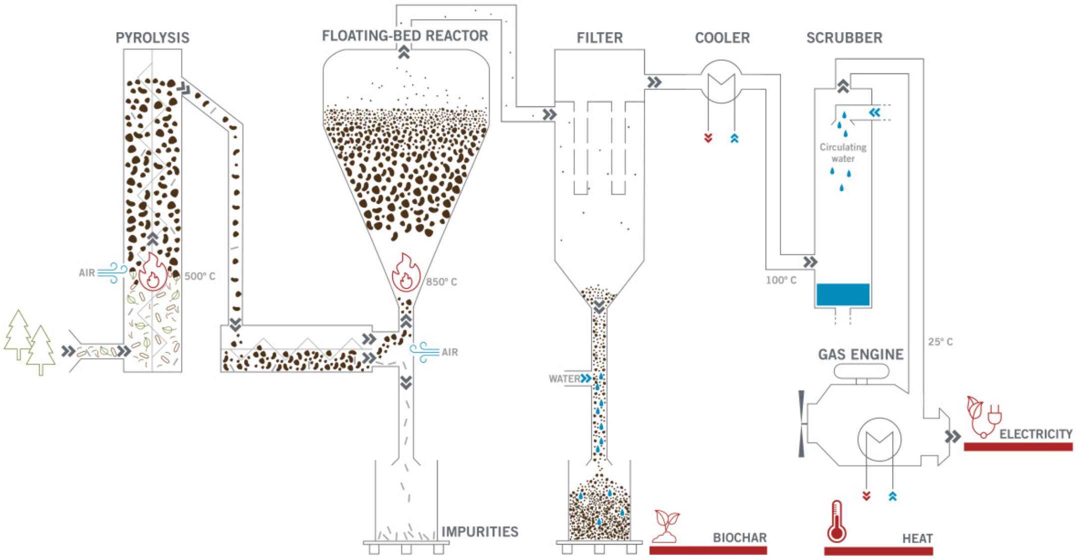


Fig. 2. PowerBox gasification setup with core unit: floating-fixed-bed-reactor.

During the gasification process, the particles pass through the floating-fixed-bed. As a consequence of heterogeneous reduction reactions, the particle size declines until the char pieces reach the upper side of the bulk. Depending on the individual particle sinking speed, the residual biomass char particle fraction is transported by the product gas stream into a hot gas filter system. After passing a cooling unit, the producer gas is cleaned by a fuel specific water scrubber before the usage in a combustion engine. The gasification setup with the floating-fixed-bed reactor is shown in figure 2.

## 3. Results and discussion

During all continuous operation test runs, a detailed mass- and energy balance has been calculated and analyzed. Some typical parameters are given with the following Table 1 which have been logged during 100-hour test runs.

One of the most important criteria of a modern gasification system is a steady gas composition and quality. The result of the continuous monitoring of the gas composition over a representative 100-hour test run is shown in Table 2.

Beside the composition of the main gas components, the load with tar and other impurities must be below certain values for utilization within gas engines [5]. The test run demonstrates a steady >99 % degradation of tars within the floating-bed reduction reactor to an uncritical sum value <50 mg/m$^3$ u.s.c. even before gas cleaning throughout the whole test runs.

Several research groups are focusing on tar reduction methods to reach similar low tar contents in the producer gas for other gasification concepts. Especially the gasification temperature and residence time as well as the catalytic tar reduction potential of gasifier char show a high influence onto the tar conversion [6]. Based on these findings, internal unpublished investigations have been carried out to describe the tar reduction mechanisms in dependence of the gasification temperature and gas residence time in the floating-fixed-bed gasifier. The results prove the influence of the gas residence time in the char bed onto the tar concentration in the product gas and show also the possibility to lower the gasification temperature without exceeding tar concentrations.

Beside the good tar cracking behavior of the floating-fixed-bed-system due to a relative long residence time of the gas in the reactor and also the low pressure drop, the avoidance of channeling or compaction of the char bed are the main advantages of the system which lead to a nearly tar-free product gas [7].

Table 1. Key figures – 500 kW pilot plant.

| Parameter | Value | Unit |
|---|---|---|
| Biomass Input | 100 | kg/hr dry matter |
| Air ratio pyrolysis | 0.09 – 0.11 | |
| Air ratio gasifier | 0.21 – 0.27 | |
| Air ratio total | 0.3 – 0.38 | |
| Filter dust | 4 - 5 | kg/hr |
| Gas | 250 - 280 | $m^3$ u.s.c./hr |
| Heating value | 4.9 – 5.2 | MJ/$m^3$ u.s.c. |
| Cold gas efficiency | 74 - 80 | % |

Table 2. Exemplary producer gas composition.

| Producer gas component | Average values (n=5) | | | |
|---|---|---|---|---|
| $H_2$ | 18.1 | ± | 0.28 | [%] |
| CO | 20.2 | ± | 0.20 | [%] |
| $CO_2$ | 15.4 | ± | 0.16 | [%] |
| $CH_4$ | 2.0 | ± | 0.20 | [%] |
| | | | | |
| Sum BTEX | 10.8 | ± | 4.3 | [mg/$m^3$ u.s.c.] |
| Sum PAH | 0.035 | ± | 0,004 | [mg/$m^3$ u.s.c.] |
| Grav. Tars | 15.3 | ± | 2.9 | [mg/$m^3$ u.s.c.] |

## 4. Conclusions

The floating-fixed-bed technology closes the gap between small-scale fixed-bed (up to 300 kW thermal power) and fluidized-bed (starting from 10 MW thermal power) gasification plants. The system provides a low tar product gas for the utilization in decentralized CHP-plants, which already demonstrated its long-term reliability with the use of wood chips in a pilot plant and several commercial plants, as well. Test runs of the adapted reactor design for the utilization of pelletized fuels show promising results and prove the flexibility of the technology in terms of fuel flexibility.

## 5. Outlook

Based on the project findings, in a follow-up project PowerBox² started in 2013, the setup of the gasification plant will be optimized for the gasification of industrial pellets in order to utilize alternative biomass, especially forestry residues (needles, bark etc.), agricultural and communal residues. The further development for pellets applications allows the utilization of a broad range of fuels.

Beside the adaption of the gasification setup, further investigations will be carried out to clarify the influence of ash constituents onto the gasification reactions as well as the transferability of these findings onto the operational parameters of the gasification plants.

Biochar, the solid biomass residues separated from the product gas stream, show the potential to be a valuable by-product of the gasification system with further use for different purposes like soil enhancement, activated carbon, etc. Different utilization possibilities are currently under examination.

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